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Report of the Workshop on Aviation Safety/Automation Program

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PREFACE

As part of NASA's responsibility to encourage and facilitate active exchange of information and ideas among members of the aviation community, an Aviation Safety/Automation workshop was organized and sponsored by the Flight Management Division of NASA Langley Research Center. The one-day workshop was held on October 10, 1989, at the Sheraton Beach Inn and Conference Center in Virginia Beach, Virginia. Participants were invited from industry, Government, and universities to discuss critical questions and issues concerning the rapid introduction and utilization of advanced computer-based technology into the flight deck and air traffic controller workstation environments.

The workshop was attended by approximately 30 discipline experts, automation and human factors researchers, and research and development managers. The goal of the workshop was to address major issues identified by the NASA Aviation Safety/Automation Program.

This report documents the results of the workshop. The ideas, thoughts, and concepts were developed by the workshop participants. The findings, however, have been synthesized into a final report primarily by the NASA researchers. The use of notes and taped recordings of the sessions facilitated this documentation. Many thoughts and concepts have been summarized so as not to identify any comment or thought with a particular individual or organization. This format was chosen to facilitate a free exchange of information and ideas at the workshop.

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CONTENTS

Preface iii

Introduction 1

Working Group Reports

Situation Awareness 3

Functional Validation 9

Technology Transfer 13

Summary and Conclusions 21

Appendices

A. Source Document: Situation Awareness–Critical Phenomenon or Ill-Defined Concept? 23

B. Bibliography: Situation Awareness 35

C. List of Participants 41

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LIST OF FIGURES

Figure 1. Aviation Safety/Automation Program Stakeholders and Lines of Communication 10

Figure 2. Evaluation Process 11

LIST OF TABLES

Table 1. Program Products to be Transferred 16

Table 2. Technology Transfer Points 17

Table 3. Process for NAS Technology and Transfer 18

Table 4. Preconditions for Program Success 19

INTRODUCTION

The National Aeronautics and Space Administration (NASA) has initiated the Aviation Safety/Automation Program to address the research and development of human-centered automation which would assist humans to attain increases in performance within the flight deck or ATC workstation, to monitor human performance, to detect and warn of human errors, and to manage contingencies.

To encourage effective communication and the exchange of ideas with the aviation community, a workshop was conducted to address three major issues identified by the program. These issues were (1) the measurement and evaluation of situation awareness, intent, and performance; (2) functional validation of automated systems, especially AI/expert systems; and (3) successful completion of the program considering the need for technology transfer. The workshop's participants were divided into three parallel sessions to address these questions, then brought back together in a plenary session.

The Situation Awareness Group was asked to identify effective means of measuring and evaluating situation awareness, crew/controller understanding, anticipation, intent, and performance. They were also asked to consider complacency, vigilance, and boredom, and to identify voids in the research knowledge base. With the belief that increasing levels of technology and automation will be employed in the flight deck and controller workstations, the ability to define and evaluate the effects of automation on situation awareness has long been desired.

The Functional Validation Group was asked to identify the level of functional validation of automation concepts/expert systems developed within the program that should be achieved. The methodology to obtain this level would also be identified. Guidelines and protocols are also needed to evaluate the performance and performance limits of knowledge-based systems. Methods are required to assure that an intelligent, automated system will not command an operating mode that could cause the system to deviate from its safe operating envelope.

The Technology Transfer Group was asked to discuss effective means of technology transfer and how a successful completion of the program could be realized. Simulation and flight demonstrations of research results as a means of effective technology transfer were also discussed. It is desired that the research products from this program be utilized by the aviation community, so candid discussions of past successes and failures were encouraged.

Final Report of Working Group on

SITUATION AWARENESS

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Introduction

The Situation Awareness group was asked to address the issues of measuring and assessing Situation Awareness, crew/controller understanding, anticipation, intent, and performance. With the belief that an increasing level of automation will be brought to the cockpit, it is important to be able to measure and assess these concepts so that meaningful evaluations of human interaction with specific automation concepts can be made.

Background

Historically, the term "Situation Awareness" primarily has been associated with attitude awareness, or, in the military, with knowing the relative positions, speeds, and directions of flight of friendly and hostile aircraft during a tactical battle. Today, however, Situation Awareness has taken on a much broader definition.

Definition: Situation Awareness consists of two components: (1) the operator's knowledge of the current physical and tactical environment; and (2) the process or strategy by which the operator switches attention to the multiple tasks being performed in order to keep that knowledge up to date.

The specific physical and tactical aspects of Situation Awareness must be defined explicitly for the specific task environment. Generally, the physical environment will consist of X and Y position (longitude and latitude), altitude, aircraft attitude, heading,

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speed, and other task-specific items. The tactical environment is highly task specific and could include such things as fuel remaining to fly to an alternate airport, height above ground, time to make a heading change, or altitude at which to level off. Situation Awareness is by its very nature an inferential process on the part of the operator. It is not merely a collection of information coming in to the operator, but an active process by which the human operator infers concepts/models from the information coming in, organizes them, and combines them in various ways to perform necessary tasks. The process involves reducing the data down to as simple a level as possible. For instance, if the operator knows that the flaps are at a certain setting, the slats are extended, and the landing gear is down, then the airplane is in a "landing configuration." Generally, this is all that is needed; however, at other times more specific information may be needed.

Situation Awareness should be considered to be a useful heuristic that allows us to focus on the different kinds of psychological activities and properties that are tractable to the researcher. Therefore, explicit definitions of these psychological activities or properties being investigated should be stated clearly in the research description.

Operational Considerations

The following operational aspects of Situation Awareness were identified:

(1) Aircraft Path in Space (Navigation, Lateral Position, Vertical Position);

(2) Aircraft State (Fuel, Sub-system, Configuration);

(3) Position with Respect to Other Traffic (Terminal Area Operations, Sequencing on Airways); and

(4) Communication (Air Traffic Control, Company, Passengers).

Situation Awareness Issues

The following issues were identified as critical:

(1) What is a useful definition of Situation Awareness?

(2) What procedures or techniques should be used in measuring Situation Awareness?

(3) Should Situation Awareness be measured as an absolute quantity or as a change from a previous level?

(4) Are there different types of Situation Awareness, and if so how does one know that the correct type of Situation Awareness is being measured?

(5) What is the nature of the relationship between Situation Awareness and Performance?

(6) To what degree do Automatic systems give the operator feedback to enhance Situation Awareness?

(7) When a simulation scenario is stopped to obtain subjective evaluation of Situation Awareness, can the simulation scenario be continued or should it be stopped, and a new scenario started?

Possible Measurement and Evaluation Techniques

Crew/Vehicle Assessment
- Aircraft flight path deviation
- Frequency of control inputs
- Latency in achieving navigational goals
- Accuracy of following procedures
- Errors
- Response Time
- Subjective Responses (Questionnaire, Rating Scales)
- Workload Assessment (Physiological, Subjective, Performance)
- Visual Scan

Performance History
- ASRS Database
- Error Rates
- Questionnaires/Surveys
- Flight path error
- Subjective Opinion

Specific Situation Awareness Assessment Techniques

Situation Awareness Global Assessment Technique (SAGAT)
(Endsley, 1988)

The following methods were identified for evaluating of specific situational awareness concepts:

(1) Problem solving research paradigms (Errors, Slips, Mistakes, Response Time Latency, Anomaly Detection Accuracy, Decision Making, Judgment);

(2) Questionnaire (Quantitative, Situation Queries, "What If" Queries);

(3) "Workload" Measurement Techniques (Physiological, Subjective, Performance); and

(4) Visual Scan (Eye Point-of-Regard).

Crew/Controller Understanding

A definition of Crew/Controller Understanding was not agreed upon during the workshop, however, one possible definition was submitted prior to the workshop as "the extent to which any messages or instructions between the crew and the controller are understood as the sender meant to convey them". Crew/Controller interaction is one of the sources of Situation Awareness. It is analogous to other information sources, such as displays, aural cues, alerts, warnings, and information from other crew members.

Many of the same measures used for Situation Awareness could be applied to the Crew/Controller Understanding Issue. In addition, the following measures should be considered:

(1) Compliance with Commands;
(2) Response Latency;
(3) Accuracy in Interpreting Messages;
(4) Types of Errors;
(5) Information Transfer Rate; and
(6) Questionnaire.

Anticipation

To some extent, the degree to which a pilot or other operator can anticipate and prepare for seemingly unexpected events is another measure of Situation Awareness. Two types of activities were discussed which help the crew anticipate events: preparatory processes and communication. In a preparatory process, the crewmembers anticipate their own needs and prepare for those future needs either overtly or covertly. Most forms of training are overt, while mental rehearsal, in which a crewmember uses periods of relative inactivity to mentally rehearse upcoming tasks and to consider possible contingencies, is covert. A serious research problem remains in that it is very difficult to detect and quantify covert preparatory processes, which actually increase "off-peak" workload temporarily, and to correlate these processes to better task performance. Communications, either with or between other aircraft and Air Traffic Control (ATC), can also help the crew anticipate future workload demands and prepare properly. It was mentioned that the use of DataLink may have an impact on this source of information.

Intent

With regard to system knowledge of operator intent, it was proposed during the workshop discussion that intent inferencing is best described as maintaining or improving the Situation Awareness of the aircraft systems and automation. For the automation to effectively carry out its assigned duties, it needs to be aware of much of the same information as the operator. In addition, it needs to be aware of what the operator is doing now, how this fits into his overall goal, and what he plans to do in the future. While this level of understanding does not exist in current cockpits, its development may be necessary to provide the forms of advanced decision aiding envisioned by many. A simpler form of intent inferencing may be possible using eye point-of-regard, so that the system can provide the information it determines the crewmember is seeking.

It is also interesting to note that pilots in current-generation aircraft are doing intent inferencing themselves with respect to the automation. Questions such as: "What is the system doing now?" "What is it going to do next?" "Why is it doing that?" are frequently cited as examples of the difficulty of maintaining good Situation Awareness.

Summary

A working definition of Situation Awareness was presented in which Situation Awareness was conceptualized as consisting of two components: (1) the operator's knowledge of the current physical and tactical environment; and (2) the process or strategy by which the operator switches attention to the multiple tasks being performed in order to keep that knowledge up to date. Because of the inferential nature of Situation Awareness, it cannot be quantified directly, and must be derived through the measurement of other parameters. A number of the possible measurement and evaluation techniques were presented.

Final Report of Working Group on

FUNCTIONAL VALIDATION

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Introduction

The Functional Validation Group was asked to address issues concerning the level of validation (functional only) that should be achieved in the Aviation Safety/Automation Program for the new automation concepts produced.

The remainder of this report describes the scope of the specific issues that were addressed by the working group, the stakeholders in the validation process for the Aviation Safety/Automation Program, validation as consensus, and the evaluation process for new automation concepts.

Definition of Functional Validation and Scope of the Working Group

Validation is an extensive process. It involves defining the requirements for a given problem, and from those requirements deriving a solution. One concern is determining whether the correct problem is being solved; i.e., whether the requirements are correct for the problem. Verification is the process of determining whether the solution concept satisfies the requirements. Although this group was tasked to address the entire validation process, the entire process was considered too large to address in the given amount of time. The group decided, therefore, to focus on the question of verification: assuming that the set of requirements is given, how should the solution concept be verified? Two aspects of verification for concepts, such as the ones developed in the Aviation Safety/Automation Program, are research evaluation (often involving human-in-the-loop experiments) and FAA certification. The outputs of the evaluation are important inputs to the certification process. Although the group discussed certification, the emphasis was placed on the evaluation process. The group also decided that consideration of the evaluation of

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advanced automation concepts was more appropriate, rather than a particular technology such as artificial intelligence.

The Stakeholders

The group decided that identification of the stakeholders in the validation of Program outputs was important. The outputs of the Program are: (1) guidelines; (2) early warnings of technology considerations; (3) technologies and concepts; and (4) methodologies for validating those technologies and concepts.

The stakeholders in the validation of Program outputs were determined to be NASA, airframe manufacturers, airlines, the FAA, and the public. The lines of communications among the stakeholders are depicted in Figure 1.

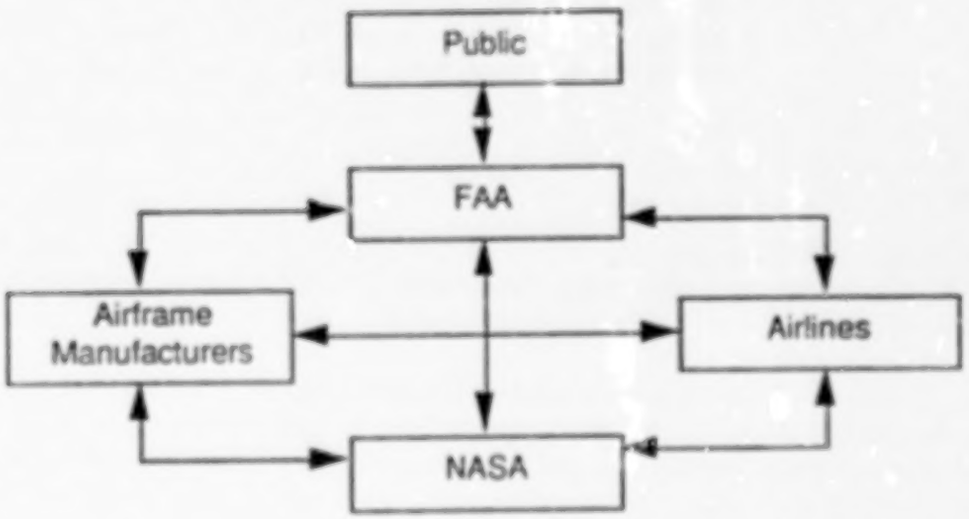

Figure 1. Aviation Safety/Automation Program Stakeholders and Lines of Communication.

Validation As Consensus

The group observed that the current approach to validation of new automation is a consensus-building process, rather than a formal proof, because formal proofs are not possible. Therefore, regardless of the approach taken to show that a concept meets the requirements, the hope will be for the relevant stakeholders to conclude with a consensus.

The consensus is developed iteratively. First the developers must convince themselves that the concept is satisfactory. Sometimes this can be done by analytical means, and sometimes just by interacting with the concept. This ability to use interaction as an alternative is important because analytical means are not always available. The next step usually involves broadening the circle of consensus to include other stakeholders. This

process continues until all relevant stakeholders are satisfied that the concept is viable. During this process, it is often realized that the concept has limitations. These limitations are noted, but there is often enough consensus to proceed with the process. This is very different from a proof.

Evaluation Process

The evaluation process is iterative, as shown in Figure 2. Functional validation does not occur at any one point in the process. Rather, functional validation is the entire process of formulating the problem to determine requirements, developing a solution, and gaining experience with the solution concept. Some of the initial experience is gained while developing the initial solution concept. Ongoing experience is gained during the entire evaluation process. This type of evaluation process may be even more important for concepts that use artificial intelligence (AI) technology, because suitable analytical evaluation techniques are often lacking.

The question remains of how much of this evaluation cycle is necessary before the solution concepts can be transitioned to the user. Addressing this question is the research goal of full-mission simulation tests in which the research concept is compared to some baseline. It was strongly noted that part-task simulation is a very important step but is not sufficient. Although part-task simulations are important, full-mission simulation is necessary to test the interaction of the concept with other parts of the overall system. This interaction and integration with other parts of the system is particularly important to the FAA, because a major focus of that agency is to examine how a new concept interacts with the existing system.

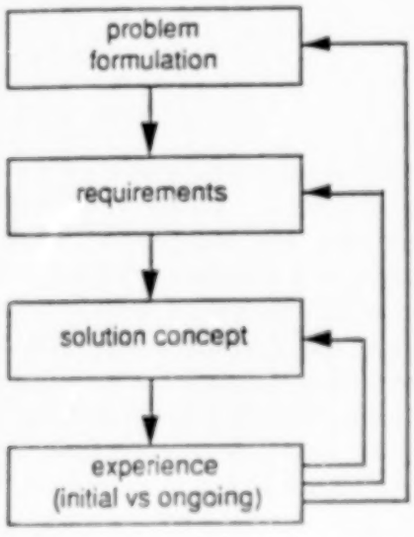

Figure 2. Evaluation Process.

Although full-mission simulation was agreed upon as a minimum for functional validation, not all the workshop participants agreed that it represented the end of the evaluation process. No consensus was reached among the group members regarding the need for flight test. Flight tests were viewed as increasing the confidence in some concepts, while being of little help in others. For example, a flight test could not be conducted in which an actual fault was introduced to test a fault management system such as Faultfinder. The group agreed that it is important to remember that flight tests are not intended to prove the absence of errors in a system, but rather are intended to increase confidence in a system. For some solution concepts, flight tests may be necessary to gain the desired level of confidence.

A very important point made in the working group was the importance of involving the potential customers (primarily the airframe manufacturers) very early in the research process. It was considered inappropriate to fully develop and evaluate a concept, and then expect the users to incorporate it into their systems. The problem that arises is that the organization will not be familiar with the concept and will not understand its capabilities and limitations. It was believed to require a great deal of effort to transfer a concept if there is no early involvement.

The utility of the experience gained in the evaluation process relies heavily on scenarios. It was observed that it is important to remember that as scenario complexity increases, the cost associated with developing and using the scenarios increases. Cost also increases as the set of scenarios is enhanced to achieve increased coverage. Therefore, there is often a tradeoff between scenario complexity and coverage. Often the evaluation is designed to a fixed cost level, so some compromises may be necessary. If the concept is determined to be viable in this limited evaluation, it is then placed in an environment where it will receive ongoing use. This use contributes to the ongoing validation of a solution.

Summary

The working group identified the stakeholders in the validation of concepts and technology produced by the Program. These stakeholders included the airframe manufacturers, the FAA, the airlines, and the public. The group agreed that the current approach to validating automation is a consensus building process, rather than a formal proof of correctness, because a formal proof is not possible. It was agreed that a consensus building process will also apply to functional validation of the Program concepts, and that some of this will occur during the evaluation of the concepts. The evaluation will be an iterative process, and should include taking concepts to full-mission simulation at least. The group noted it is highly desirable for the potential customers of the Program concepts, especially the airframe manufacturers, to be involved early in the research and evaluation process The group also observed that the utility of experience gained in the evaluation process relies heavily on the scenarios used.

Final Report of Working Group on

PROGRAM SUCCESS AND TECHNOLOGY TRANSFER

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Background

The Program Success and Technology Transfer group was asked to address the issue of defining means by which to assess the success of the program and to enhance technology transfer.

Introduction

The group discussed the fact that there are basically two ways of measuring the success of research programs. One is through assessing the impact of research products and the other is through assessing the quality of the work being performed. Implicit in the concept "technology transfer" is the assumption that a program's life-cycle is more or less linear and that the various program products can impact current problems in aviation safety as well as influence future generation aircraft and systems designs. The interdependency between program success and technology transfer is complex and the timing of the assessment is crucial for arriving at a sought-after answer. For example, it may well be that we can get different answers to the question, "are we successful ?", one year from now, at the end of the program's budget cycle, or ten or more years from today. In addition to these maturational considerations, the various types of program products may call for differential treatment in terms of their relative suitability for transfer (or measurement of success).

The group suggested that the most effective means for accomplishing the transfer of research products is directly tied to the degree of movement of people and information among and between industry and government agencies in this country. Several specific solution paths for successful technology transfer were discussed in light of a cursory analysis of current impediments. These are detailed in a later section.

What Gets Transferred?

Traditional transfer vehicles, such as NASA Technical Memoranda or other journal-type reports constitute a traditional style of information transfer but were judged by this group as relatively unsuccessful in terms of having near term real-world impact. More recently, software tools, when used and applied by NASA "customers" to their own R & D efforts, are becoming an immediately sought after product that can be easily disseminated to the relevant players in the community. These products can have an important impact upon future developments.

Fully engineered systems and designs as end-products are most closely linked to the term "technology", but the working group felt that, in the human factors arena at least, systems constitute more of a methodology embodied in a set of tools rather than unitary end-products that can be adopted "as is" for use in the operational aviation community. In fact, human factors contributions to the research and development store of accumulated system knowledge (simulations were included in the discussion) is by nature difficult to assess and transfer ("when the best human factors work is done nobody notices, only when problems arise, i.e., something goes wrong, are human factors people called upon").

A primary way to forestall these adverse forces is to ensure that human factors professionals are an integral part of the research and development process. Interdisciplinary working teams made up of representative experts from both government and industry were thought to be the optimal vehicle for accomplishing effective technology transfer.

Impediments to Technology Transfer

Several impediments to technology transfer exist, including economic constraints, socio-historical factors, and domain-inherent limitations that hinder rapid, transfer progress.

Economic Forces. – Like other companies, the airline industry is basically economically motivated. Manufacturers will build what their customers, the airlines, demand. Different customers will pose different requirements since the cause-effect link between good design and accident rate is so precarious. In the absence of hard data derived from comparing "design A" with "design B" in terms of their respective potential for producing differential human error rates, the customer will state his requirements based on cost, subjective preference and/or tradition, as well as other, hard-to-track, criteria. NASA must therefore invest time in educating all the customers, especially the airlines.

Criticality of a potential error is also an important consideration in the success of new designs. For example, "tuning radio frequencies" was mentioned to illustrate that mistakes are made all the time, but that the potential cost of a redesign in this domain far outweighs the perceived benefit. The economic impact of design on pilot training or training of maintenance personnel deserves attention. A design idea may not be able to be "sold" based on good human factors principles; however, if one can show that savings

may be achieved in the training area with the particular design, the idea will be popular and likely to be adopted.

Measurability. – A measurement problem exists when discussing human factors variables. For example, which features in an avionics display lead to incidents/accidents in contrast to those which are simply annoying? It is also difficult to get accurate baseline measures on everyday mistakes in the cockpit. Pilots are generally very good at catching most of the errors that result from suboptimal design. In general, if one can show (in high fidelity situations) that a feature will reduce the number of incidents or errors, this constitutes sufficiently compelling evidence to convince both the customer and the manufacturer that this is something they want and need. On the other hand, a simple "study" based on some "academic" theoretical considerations is likely to be ignored by the aviation community.

Research and measurement in the training process was also suggested as an indirect vehicle for measuring the "goodness" of automation. Several U.S. carriers are following the trend started by their European counterparts of hiring ab-initio-pilots out of necessity. If a type of design can help a pilot with little experience make fewer errors, then the automation design will be deemed successful by the airlines. In other words, cockpit human factors must be tailored to address issues that will reduce training requirements (hence cost) for the inexperienced pilot.

Socio-Historical Forces. – Research and development in the aviation community is still largely driven and dominated by the aerodynamics and structural engineering contingent of the airframe manufacturers and not by the end user, the pilot. Only recently has there been a perceived shift among customers benefiting the avionics side. Next generation aircraft are still being specified primarily in terms of structures and propulsion and not in terms of crew performance and cockpit design. If early human factors considerations arise, they are certainly heavily outweighed and overshadowed by their more influential "metal-bending" counterparts.

One factor that may seriously affect human factors efforts and the Aviation Safety Automation program in the next several years is public opinion. It was pointed out that, at the current rate of growth in the airline industry, the worldwide accident rate, in terms of sheer numbers perceived by the public in only 5 years time, may be as high as one major accident every 3 weeks. The present day culprit "human error" will continue to arise as a causal factor, and public outcry may demand more "human factors" consideration.

Type-Rating and Training. – The airlines presumably want their pilots to have type ratings that cover all the aircraft in their fleets. Yet, airlines will resist new avionics technology if it increases the likelihood of errors when pilots transition back to older technology aircraft. This line of reasoning was felt to be the case even if a "better mousetrap" was available. If there were an increased effort to standardize aircraft types (by manufacturer at least), then there would be an improvement in the ease of transferring technology.

Incompatibility with Ground Control. – Another major impediment to continued progress in cockpit technology is the incompatibility between the sophistication of available cockpit technology and the technology used by ATC. This mismatch is thought to be responsible for defeating much of the potential benefits derived from innovative cockpit research such as advanced flight management systems concepts.

Proprietary Information. – In order for innovative ideas and methodologies to flourish it is important to exchange information freely. A major stumbling block to the free flow of information between government research labs and the aviation industry (avionic and airframe manufacturers) is the proprietary nature of advanced information. Mutual benefit can be derived if the manufacturer allows government personnel access to their research labs and NASA invites manufacturer personnel to participate in their research endeavors. This interchange would go a long way toward developing mutual education and training and ensure relevancy.

Strategies for Technology Transfer

A list of potential research products is given in Table 1. These should have an impact on improved training and accident prevention. It should also be noted that the transfer of products or methodology can each have an impact on air transport operations. Products accomplish this simply by being adopted, whereas methods and data influence how future technology actually gets developed.

Table 1: Program Products to be Transferred

CATEGORY	SPECIFIC ITEMS
Information	Tools, Measures, Data, Tactical Support
Technology	Systems, Designs, Hardware
Methods & Methodologies	Reports, Software, Expert Systems
Guidelines	Training, Operational Design
Candidate Designs	Early Prototypes
Technical Support	Expertise through People Exchange

Training Impact. – The research products that have an impact on training are very important to the airlines because a reduction in training due to automation translates directly into cost savings.

Accident Prevention. – Accident prevention is another important area since it is a concrete issue and usually gets the backing of everyone: the manufacturers, the airlines,

and the pilots. It is therefore recommended that human factors research should always strive to demonstrate improvements and/or recovery from known accident cases.

A related topic addresses the available research infrastructure. The aviation community should strive to standardize scenarios used in the evaluation and testing of new ideas, equipment and procedures. If this element in the research environment were fully intact and scenarios could be widely shared by the various research houses, large strides in obtaining relevant relatable data could be made. The availability to any researcher of simulators with standardized operational scenarios based on critical accident data to test technology issues is vital to having an impact on safety.

Early Involvement of People. – In order to ensure that research products reach their destination it is important to explicitly define NASA's potential customers. The research effort must involve these people at all phases to ensure technology transfer. Involvement of these people in the research effort allows immediate feedback as well as immediate dissemination of results. It also develops an advocacy group to bring knowledge to the uninformed and reluctant. Table 2 lists the potential technology transfer points in the aviation research arena.

Table 2: Technology Transfer Points

Transport Aircraft Manufacturers (domestic and foreign)
Business Aircraft Manufacturers
Avionics Manufacturers
Airlines (domestic and foreign)
Pilots (ALPA, APA)
Transport Associations (ATA, IATA)
Controllers (NATCO, ATCA)
Standards, Regulation, Certification (FAA,CAA,etc.)
Research Community (Academic and Industrial Standards)
Military Aviation (DOD)
Safety Boards (NTSB)

Past successes in human factors technology transfer have resulted from close cooperation between researchers and the airline pilots or the airlines, i.e., the end user.

"Standardize" Research Among Centers and Industry. – Besides facilitating effective dialogue, the development of standardized, compatible facilities and jointly developed scenarios and methodologies will greatly enhance productivity. A tool kit of various simulation modules, scenarios, and data collection tools can be assembled by NASA and others for exchange so that research methodology does not need to be re-invented every time an issue is to be investigated. At the moment considerable research energy is spent

on getting the necessary resources up and running rather than dealing with solutions to key issues.

Joint use research facilities with very high fidelity, two-crew, flight deck operations in realistically complex ATC simulations are needed to gather data for research with actual line pilots. In order to make a substantial impact on the aviation industry a need exists to establish an entirely new way of working together. NASA can facilitate the development and cooperation of joint working teams among industry and government. Such cooperation would be a very effective way to exchange information in a timely and informed manner and will result in accomplishing a large amount of necessary work in the shortest possible timeframe.

Joint National Research Teams. – Working in the framework of a national research unit is of benefit to all participants since better ideas are generated, people get fully trained, and investigators will take lessons learned back to their own institutions and companies. This model is borrowed from the Japanese but may be successfully applied to our own situation in the United States on any project or program with national scope.

Table 3 shows the proposed distribution of personnel during a program's life cycle. During the problem definition phase it is important to involve all interested parties. Solutions should be proposed by a smaller interdisciplinary group of experts and prototyping and testing should occur by a selected group of experts (solution authors) in a consortium-type contract arrangement.

Table 3: Process for NAS Technology and Transfer

		PARTICIPANTS		
INVOLVEMENT	PROCESS STEP SELECTED	ALL	SMALL GROUP	TEAM
NASA AND INDUSTRY	Problem Definition	X		
	Propose Solution		X	
	Prototype & Test			X
	Lessons Learned			
	Technical Support			X
INDUSTRY	Application of Solution		X	

The main message of this research model is that technology simply can not be planned from point A to point B, rather it is people who provide the critical element for making technology transfer happen. A well defined government/industry program with clear problem definitions can have a much bigger impact than just another program plan based on past government-industry relationships.

Other Suggestions

Group discussions included a host of other related issues. These can be categorized primarily into necessary preconditions for success of the program and specific suggestions for dealing with currently perceived shortcomings. Five global preconditions are listed in Table 4.

Table 4: Preconditions for Program Success

Clear and Commonly Agreed Upon Goal Statements
Economic Incentives (Industry) and Motivation (Problem Criticality)
Measurement Technology (Standardized Environment Must Exist)
Ease of Interaction (Modern Media and Management Support)
Stable Funding (Commitment by All Parties)

Simulator Working Group. – Several points of confusion exist on how to maximize the value of simulation research. Standard methodologies are lacking and there is a sense that we could obtain a lot more information out of simulator research than we are presently achieving. A working group should be initiated to discuss these issues and to look at the various simulation projects and facilities, their respective capabilities and methodology. This working group should arrive at guidelines for achieving a high degree of standardization and compatibility between government and industry research facilities.

Airline Focus Meetings. – The perception of various NASA outsiders is that there is a noticeable gap between the research being performed and the operational aspect of transport aviation. To overcome this perception it is suggested that NASA hold regular meetings with the airlines as a focal point where the researcher-participants' task is to really understand what the airlines are saying about the various operational problems. The airlines would identify and prioritize their issues and explain to the researchers the operational problems they are facing. The recent ATA National Plan To Enhance Aviation Safety Through Human Factors represents a positive step in this direction. The two points emphasized in relation to this suggestion were that (a) the technical researchers should participate and (b) there should be a thorough sampling of airline participants, not just a rotation of a small select group.

Information Exchange. – Several means for enhancing the information exchange infrastructure were discussed. Specific suggestions to stimulate heightened information exchange included the publication of a newsletter with joint contributions from industry and government researchers working on a specific problem (having one specific mandate). An electronic version of this newsletter could also be made available. Innovations such as hypermedia could serve to make demonstrations and news items an extremely stimulating and interesting forum.

The general notion of portability of software and hardware was also mentioned as a potential enhancement to information exchange and, therefore, technology transfer. We basically need to find better ways to share things quickly. "Share-ability" of information in the applied human factors domain is somewhat problematic since industry has proprietary concerns and many researchers outside specific avionics or manufacturing companies are not sufficiently informed about plans for next generation technology. What is basically needed is information access, compatibility and portability of software ("software speaks louder than words") and hardware to achieve a spirit of cooperation. The present state of affairs can be characterized as a general willingness to cooperate but lacking the necessary focus and some vital pieces of the necessary infrastructure.

Asking for Feedback. – One of the most obvious but often neglected ways of measuring success is to ask for feedback directly. NASA could seek critical feedback by exposing research ideas to the aviation industry. While the current structure of the Aeronautical Advisory Committee does some of this, it is primarily program oriented and therefore does not provide specific technical critique desired by the researchers.

One possible vehicle for this kind of feedback is for NASA to send out survey questionnaires on a fairly regular basis asking for opinions from industry on how much impact NASA-sponsored work has had on them or how helpful NASA reports have been. Technology transfer in this sense becomes clearly a two-way path.

Summary

Human Factors Research by its nature is more difficult to track and evaluate than its engineering and technology counterparts. Multiple products exist that are candidates for "transfer", these range from avionics system concepts and designs to research methodologies and software tools. Progress on all of these fronts will result in a cumulative success path, i.e., have immediate and eventual impact on the National Airspace System (NAS). To enhance this process it is important to be flexible and responsive to voices from the operational community. People and expertise should be developed along with technology. NASA can play an important role in facilitating free information exchange and a spirit of cooperation that will help create the appropriate climate necessary for technology transfer to occur.

SUMMARY AND CONCLUSIONS

A one-day workshop was held to address three major issues identified by the Aviation Safety/Automation Program. Three groups were formed to address each issue. The first issue concerned the measurement of situation awareness. It was determined that situation awareness can not be measured directly, but must be inferred from parameters that are measuring human performance. The development of test scenarios that explicitly address the level of situation awareness in question was deemed to be very important.

The second issue concerned the functional validation of automation technologies and concepts. It was agreed that a consensus-building process should be applied to automation concepts developed within the Aviation Safety/Automation Program, and that some of this will occur during the evaluation of the concepts. The evaluation will be an iterative process and should include taking the concepts to full-mission simulation at least. It was also agreed that the experience gained in the evaluation process relied heavily on the quality of the test scenarios.

The third issue concerned the transfer of research products to the aviation community. It was determined that the research products take various forms, including information, tools, technology, methods, guidelines, and candidate designs. Several impediments to technology transfer of human factors research products were identified; economic forces, ability to measure safety benefits, historical forces (aero/propulsion/structures disciplines have been and are the major drivers). The group noted that past successes in human factors technology transfer have occurred when close cooperation existed between researchers and the airframers/airlines.

APPENDIX A

SITUATION AWARENESS–CRITICAL PHENOMENON OR ILL-DEFINED CONCEPT?

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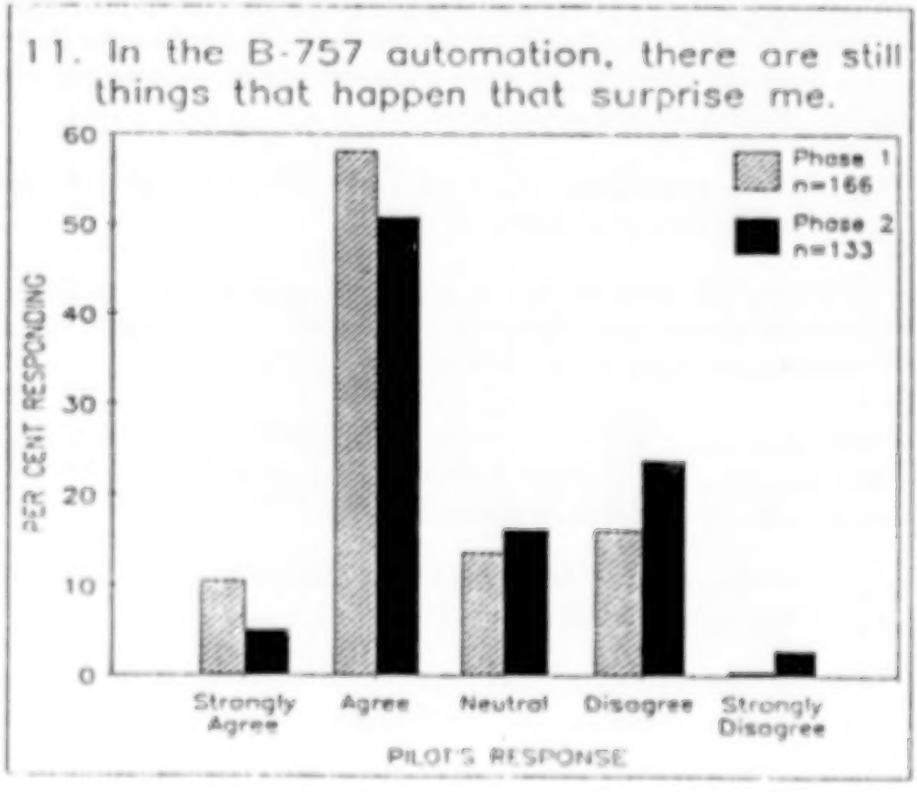
Introduction

Situation awareness is supposed to be an essential prerequisite for the safe operation of complex dynamic systems. Especially in the aviation domain, the term has become one of the most fashionable performance-related concepts since recent accidents and incidents have triggered concerns about the potentially disadvantageous effects of cockpit automation on situation awareness. This problem is being addressed by major research plans (e.g., National Plan to Enhance Aviation Safety through Human Factors Improvements, ATA, 1989; Aviation Safety/Automation Research Plan by NASA, 1988) and reflected by research findings like the following (adapted from Wiener, 1989):



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One of the major reasons for the impact of automation on situation awareness is seen in the associated changes of level and timing of feedback. Whereas manually flying a plane provides immediate low-level feedback of the consequences of each input, automated systems involve longer time-constant feedback loops. Pilots are informed about the system's state and behavior at a very high level of overall outcome of a variety of activities. Maintaining awareness becomes difficult as the evolution of situations and the overall mission is no longer perfectly transparent.

Despite the concept's popularity, a widely accepted definition of situation awareness is still missing. Processes involved in achieving and maintaining it are not yet completely understood. Surprisingly enough, research is already going on that aims at improving situation awareness by designing new cockpit systems and displays.

This paper is an attempt to fill the above-mentioned gaps by (a) looking at the cognitive basis of situation awareness; (b) giving special consideration to the meaning of the term "awareness", which is critical for developing appropriate assessment and manipulation techniques; and (c) suggesting possible new approaches to the investigation of situation awareness.

The Concept of "Situation Awareness"

Both the commercial and the military aviation community have proposed a variety of definitions of situation awareness. The following list presents some examples to illustrate their differences in abstraction level and degree of comprehension. Those aspects referring to the definition of "awareness" are underlined.

(1) "...the pilot's knowledge about his surroundings in light of his mission's goals..." (Whitaker and Klein, 1988)

(2) "...It means that the pilot has an integrated understanding of factors that will contribute to the safe flying of the aircraft under normal or non-normal conditions..." (Regal et al., 1988)

(3) "...the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future..." (Endsley, 1988)

(4) "...where: spatial awareness (the pilot's knowledge of his location in space and of the spatial relationship between objects)

what: identity awareness (the pilot's knowledge of the presence of threats and their objectives and the pilot's awareness of system state variables)

who: responsibility or automation awareness (knowledge of who is in charge)

when: temporal awareness (knowledge of the occurrence of events as the mission evolves)..." (Harwood et al., 1988)

(5) "...the pilot's knowledge of:

(a) where both friendly and enemy aircraft are and what they are doing

(b) what the pilot's flight knows and what the flight's options are for offense and defense

(c) what other flights know and what their intentions are

(d) what information from above is missing..." (McKinnon et al., 1986)

These definitions, as well as most others in the aviation literature, basically address two issues: (a) the essential components and (b) the temporal dimension of situation awareness.

Components of Situation Awareness

Pilots need to pay attention to a large amount of data from a variety of sources in their environment such as cockpit instruments, other crew members, and the plane's vicinity. Many definitions of situation awareness try to define in detail which part of this information is critical for the pilot. Such efforts suffer, however, from the fact that, in dynamic environments, the relevance of data depends on their context and will therefore vary within and between flights "as a function of specific task, the environment, and the tactical objective" (Hamilton, 1987).

Rather than specifying the essential components of situation awareness, it seems more important to understand what factors may affect the acquisition and processing of data in general and how they can be counteracted. Factors that would deserve further consideration in the aviation context are, for example, lowered alertness as a consequence of vigilance decrements and fatigue or the effects of time pressure:

- Vigilance decrements are known to occur after as little as 20 minutes into a task and may cause such problems as narrowing of perceptual focus or an increasing number of attention lapses that in turn result in missing data. However, it is not yet clear whether this concept is only true in the context of simple monitoring tasks or whether it also holds for complex environments like the flight deck.

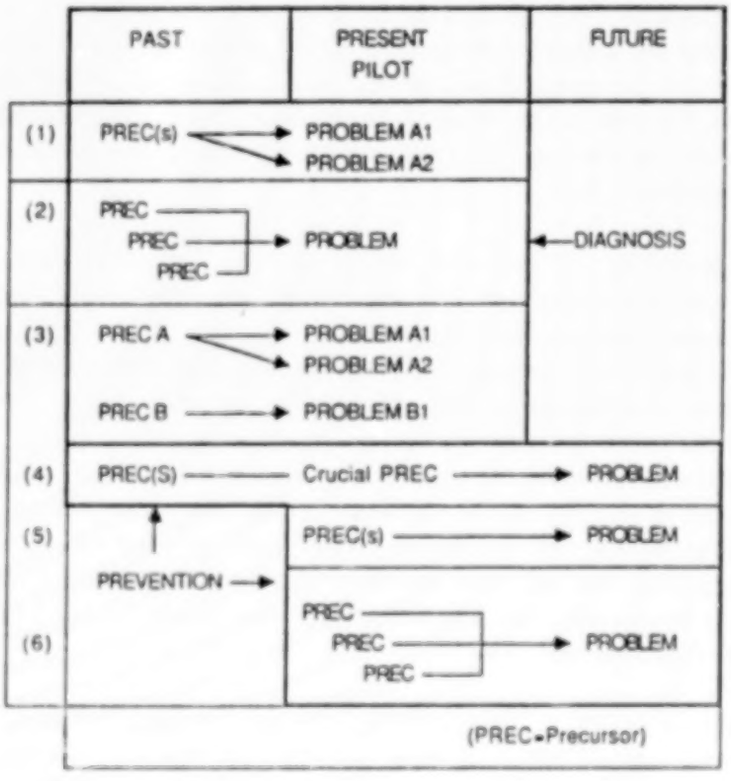
- Fatigue can result in, for example, the loss of cohesive perception; i.e., the pilot perceives all relevant data one by one but can not integrate them to an overall picture of the situation. With increasing fatigue, the pilot may

also have difficulty in accurately recalling previous flight events when required.

While most definitions of situation awareness only talk about the need to be aware of available data it can be as fatal not to notice that some information is missing. If the pilot erroneously assumes that he is on track he may run into trouble if he actually needs missing information in an emergency situation when time constraints do not allow him to search for it.

Temporal Dimension of Situation Awareness

In dynamic environments like the flight deck, minor deviations or failures that are uncritical in themselves may evolve and interact over time to become a major threat. Therefore, it is important to observe them, keep them in mind, and integrate them over time. Recurrent self-contained and isolated situation assessments are not sufficient. The goal must be an active model of the world that is continuously updated in accordance with ongoing events and trends. Temporal awareness is important for understanding and solving problems that are caused and influenced by precursors in the past. It is also essential for the prognosis and prevention of potential problems in the future on the basis of available data (see Endsley, 1988; Harwood et al., 1988). The following figure sketches some scenarios that require temporal awareness in order to cope with an existing or a future problem:



As indicated by the figure, problems can evolve in a variety of ways, such as:

A single problem may be caused by several precursors, occurring either at the same time (case 5) or one after the other (cases 2 and 6). One single precursor can result in multiple problems (case 1). A variety of precursors may not be critical in themselves but cause a problem if one additional crucial event happens (case 4). Or the pilot may be confronted with a conglomeration of problems related to different precursors in the past (case 3).

Coping with one major, instant-onset, notified failure has been investigated to some extent and is part of every pilot training. The temporal aspect of more subtle and complex scenarios, however, has been largely neglected up to now. Incident reports and discussions with airline pilots indicate that this aspect does not correspond with its importance for aviation safety. Thus, it will be important to look at the risk potentials of the outlined scenarios.

Cognitive Processes Underlying Situation Awareness

While many authors try to be specific in determining the important components of a "situation", they avoid explicitly defining the term "awareness" which is often simply used synonymously with expressions like "knowledge", "integrated understanding", or "internal model of the world" (Endsley, 1988). A more thorough analysis of the phenomenon is necessary for its investigation and manipulation.

Situation awareness is based on recurrent situation assessments and the integration of their results over time. Situation assessments have been defined as "a complex process of perception and pattern matching greatly limited by working-memory and attentional capacity" (Endsley, 1988). This process is supposed to involve three different levels:

Level I	Perception of situational elements
Level II	Based upon schemata, i.e., knowledge structures stored in long-term memory (Rumelhart, 1984), which are activated by recognized patterns in incoming data, the pilot forms a holistic picture of the situation in working memory (Wickens, 1984; Fracker, 1988). This picture determines his further information search and attention allocation (Hayes et al., 1977). These processes require a high level of expertise which has been defined as "highly developed repertoires of pattern-oriented representations" (Chase and Simon, 1973).

Level III — Projection of future status and actions of situational components This level is commonly referred to as "being ahead of the plane", which—from an aviation safety point of view—should be the main objective of all research and training efforts.

A variety of problems affecting information processing (e.g., distractions, biases) can occur at all levels and would result in inadequate or incomplete situation assessments. But even if the pilot manages to overcome all potential problems and to adequately assess the situation, it still has to be determined when the resulting knowledge can be called "awareness."

The Definition of "Awareness"

Adequate situation assessments provide the pilot with valuable knowledge about his flight. Still, knowledge does not in any case imply awareness. There is an ongoing debate about the question:

- Is awareness equivalent to actually conscious knowledge (which would suggest that only information in primary/working memory should be called aware (see e.g., Anderson, 1983)) or does it comprise any knowledge than can potentially be retrieved when necessary (as an activated subset of long-term memory)?

This question refers to the distinction between consciousness being a "state" or a "stage" (see Klatzky, 1984).

In the context of situation awareness, it seems to be inappropriate to refer to awareness only as information in working memory, i.e., information "currently under attentional focus" (see Klatzky, 1984). A definition of situation awareness has to account for requirements like the above mentioned temporal aspect. A comprehensive active model of the world that is continuously being updated can hardly be stored in short-term memory, which is assumed to only hold a very restricted amount of information. Our understanding of situation awareness will therefore comprise any information that is potentially available and can be activated when relevant in order to assess and cope with a situation.

The practical reason for bothering with situation awareness is the hope to help maintain or even increase aviation safety. This hope is based on the assumption of a positive relationship between situation awareness and performance. Besides the fact that such a relationship has not yet been established, it is important to keep in mind that pilot performance is based on both fact and skill knowledge. This also makes it questionable to require "awareness of knowledge" in the sense of "conscious knowledge." Theories of memory and awareness postulate that only fact knowledge can be(come) conscious whereas "procedural knowledge structures [skill knowledge] guiding thought and action are unconscious" (Kihlstrom, 1987). The same problem is addressed by the distinction

between "explicit" and "implicit" memory. Using this different terminology, Schacter (1987) postulates that "implicit memory [skill knowledge] is revealed when previous experiences facilitate performance on a task that does not require conscious or intentional recollection of those experiences; explicit memory [fact knowledge] is revealed when performance on a task requires conscious recollection of previous experiences."

The above statements implicitly postulate an all-or-none rule of awareness. Cowan (1988) suggests that instead of a dichotomy, there may rather be a continuum: "Activation must exert a certain threshold before it becomes part of awareness."

Based on the preceding discussion, our understanding of situation awareness is as follows:

- Situation awareness refers to any knowledge—regardless of its actual level of consciousness—that can be activated and adequately processed when required in order to cope with a situation.

This phrase is not meant to be a concise definition of situation awareness. It is far too vague for that purpose; however, it can serve as a basis for an operational definition of the phenomenon in the context of specific studies.

The Assessment of Situation Awareness

The most adequate approach to investigating situation awareness in the aviation domain seems to be the staging of complex dynamic scenarios by means of full-mission simulation. This approach avoids problems of laboratory studies, for example, simplistic tasks and tools or the consideration of isolated awareness components which question the validity and applicability of results. Still, it involves difficult issues like the following:

1. Selection of Situations

   The selection of situations to be staged on the simulator should be driven by a predefined phenomenon of interest (like the concept of situation awareness) in order to focus in on specific questions rather than generally observe pilots' performance. The challenge is to translate the phenomenon from general psychological terms to a domain-specific relevant scenario. At this stage, domain experts need to be involved in order to end up with a realistic task that is embedded in a credible overall scenario in order to motivate pilots and to get valid results.

2. Adequacy of Assessment Techniques

   Up to now, situation awareness has been investigated by using either indirect approaches (e.g., performance measurements) or direct methods (e.g., freezing techniques, debriefings; see Endsley, 1989; Marshak et al., 1987).

The problem with performance measures is that a direct relationship between performance and awareness has not yet been established. Therefore, it is questionable to simply infer the degree of awareness from the pilot's behavior. Performance measures may be the only possible method to assess implicit skill-related memory as it is supposed to influence behavior without ever reaching the state of consciousness. Eich (1984) postulates that implicit memory can never be revealed in tests that require intentional remembering, for example, in a debriefing. Still, performance measures need to be supplemented by other techniques.

The application of direct measures is likely to be intrusive and thereby counteracting efforts to be as realistic as possible (e.g., "partial report procedures" involving the "blanking of displays" as used by Endsley, 1988). Or it involves after-the-fact data collection in a debriefing that may yield misguiding results because it requires context-free retrieval of information. Another potential problem of debriefings is that they can be used to rationalize or justify behavior during the experimental run rather than describe and explain it.

Promising Alternative Approaches.

We would like to suggest alternative approaches to the investigation of situation awareness. First of all, some modifications with respect to former scenario character and implementations may be helpful:

(1) The investigation of situation awareness requires the introduction of unnotified, subtle, slowly developing, and interacting problems instead of the usual instant-onset failure that is immediately indicated by an alarm. The latter can serve to investigate pilots' decision-making and problem-solving performance. But if situation awareness is the topic of interest, it is also important to test the pilot's ability to realize the existence of a problem in the first place.

(2) The simulation should last for quite a long period of time in order to allow for the realistic evolution of a complex situation that can serve as a valid touchstone for the pilot's situation awareness. A longer scenario will also provoke vigilance decrements that are likely to impair situation awareness and to reveal consequences on performance. In addition, it will help to give the pilot a better chance to adapt to the simulator.

(3) In order to guarantee the regular occurrence of all scenario events, it will be advantageous to work with a "confederate." In former studies, standard scenarios were most often achieved by manipulating the situation from outside the simulator. But more complex scenarios involving combinations of minor problems with deliberate omission and commission errors require the assistance of a "cooperating pilot"

who initiates scenario features and who can also assist in probing the pilot's situation awareness.

The assessment of situation awareness should be carried out during the experimental run in order to avoid the above-mentioned problems related to debriefings. It will be necessary to develop and test in-flight probing techniques that are not unrealistic and intrusive. They have to focus in on knowledge that is relevant for the pilot at the time of the probing. Otherwise, there is a risk of erroneously diagnosing "unawareness", just because the requested knowledge is, in general, available to the pilot but not sufficiently activated at this time. Adequate probing techniques should address different information processing stages involved in situation assessments in order to find out at which stage problems occur.

Some candidate techniques are:

- Effacing specific data from displays when the pilot can be expected to pay attention to them instead of totally blanking the display
- Asking the pilot for previously displayed information by calling him as ATC, as his company, or by addressing him as a crew member
- Having the copilot ("confederate") discuss a problem with the pilot in order to find out about his situational knowledge
- Freezing important indicators
- Introducing unnotified aircraft in his vicinity that require collision-avoidance activities in order to test for environmental awareness

It will be essential to come up with failures, deviations, or errors that require immediate, well-defined, corrective actions or information search; otherwise there will be the same discussions about the appropriateness and necessity of expected behavior that emerged in the context of workload and performance studies. Again, the cooperation with domain practitioners will be crucial in order to adequately collect and interpret the experimental data.

Summary and Conclusions

This paper emphasizes the need for analyzing the cognitive processes underlying situation awareness in complex dynamic worlds. We need to identify and understand the nature of actually existing problems in order to move beyond the current trial and error approach to improving situation awareness.

This implies that instead of further discussion of what should be the contents of awareness, research should concentrate on the question how to assess and manipulate the potential availability of information and knowledge.

The second part of the paper suggests that full-mission simulation will be the key to investigating information processing in complex dynamic worlds, but that traditional simulation approaches need to be modified in order to effectively address critical research issues. The most important methodological goal is to develop nonintrusive in-flight probing techniques to focus in on specific information-processing stages.

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APPENDIX B

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16. Abstract

As part of NASA's responsibility to encourage and facilitate active exchange of information and ideas among members of the aviation community, an Aviation Safety/Automation workshop was organized and sponsored by the Flight Management Division of NASA Langley Research Center. The one-day workshop was held on October 10, 1989, at the Sheraton Beach Inn and Conference Center in Virginia Beach, Virginia. Participants were invited from industry, Government, and universities to discuss critical questions and issues concerning the rapid introduction and utilization of advanced computer-based technology into the flight deck and air traffic controller workstation environments. The workshop was attended by approximately 30 discipline experts, automation and human factors researchers, and research and development managers. The goal of the workshop was to address major issues identified by the NASA Aviation Safety/Automation Program. This report documents the results of the workshop. The ideas, thoughts, and concepts were developed by the workshop participants. The findings, however, have been synthesized into a final report primarily by the NASA researchers.

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